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Comparison between protein functional properties of two rice cultivars

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ABSTRACT

The functional properties of proteins from a high-protein–content rice cultivar (Nutriar) were analyzed and compared with those from a usual Latin-American cultivar (El Paso 144). Isolates from brown and milled flours were prepared and their emulsifying, foaming, and hydration properties studied. The four isolates displayed a very low solubility within a wide range of moderate pH, but demonstrate a significantly higher solubility at extreme pHs (either high or low). Nutriar isolates had a significantly higher solubility and greater surface properties than El Paso 144 isolates. The Nutriar isolate from brown flour was more soluble at pH 9 than the other isolates and moreover showed the highest capacity for forming and stabilizing foams and emulsions. In contrast, the Nutriar isolate from milled rice exhibited a higher solubility and greater foaming properties at an acid pH. The surface properties and solubility were significantly correlated among the four samples. All four isolates exhibited good water-imbibition and water-holding capacities.

1. Introduction

Cereals support half of the daily per-capita protein supply of the world. Rice proteins are considered valuable because they are colourless, of bland taste, hypoallergenic and hypocholesterolemic (Ju, Hettiartachchy, & Bath, 2001). As of most cereals, the protein content of rice is not particularly high (7–9 g/100 g); but the amino-acid composition is more complete than that of other cereals, being comparable to the profile of casein and soybean protein with respect to fulfilling the nutritional requirements of 2- to 5-year-old children (Wang, Hettiarachchy, Qi, Burks, & Siebenmorgen, 1999). For these reasons, rice proteins constitute an ingredient that may assist in increasing the nutritional value of food products at a low cost, both in production and to the consumer.

Glutelins constitute the main fraction of rice proteins. Their polypeptide composition is similar to that of the legumins, but they have a poor solubility owing to a strong aggregation that occurs mainly through their extensive disulfide cross-linking (Hamada, 2000). Relatively pure rice proteins can be produced by alkaline extraction of standard rice flour followed by isolectric precipitation (Chandi & Sogi, 2007). Depending on prevailing conditions such as the nature of the particular rice cultivar and degree of milling, the protein content of such preparations can range from 65 to 90 g/100 g (Shih & Daigle, 2000). Rice-protein isolates and concentrates have also been prepared enzymatically by protease and/or glycosidase hydrolysis (Hamada, 2000; Jiamyangyuen, Harper, Srijesdaruk, & Kumthonglang, 2005; Tang, Hettiarachchy, Horax, & Eswaranandam, 2003).

A protein ingredient of choice must present, in addition to good nutritional properties, a suitable degree of functionality to make food tasty and appealing. A protein's degree of functionality is tightly related to its structural characteristics (Kinsella, 1982); which, for their part, are influenced by the conditions of the protein's preparative milieu. The functional properties of a protein ingredient depend on its suitability to the food product in question. Many formulated foods come as foams or emulsions, thus having proteins with good surface properties and solubility; whereas others need an insoluble protein with high capacity for water absorption and retention in order to give the food an optimal texture.

Most of the functional properties of rice proteins have been studied in rice-bran–protein preparations and their hydrolysates (Bandyopadhyay, Misra, & Ghosh, 2008; Chandi & Sogi, 2007; Hamada, 2000; Tang et al., 2003). There is also some information about functional properties of the endosperm-protein fractions (Ju et al., 2001) and of glutelins (Agboola, Ng, & Mills, 2005; Anderson, Hettiarachchy, & Ju, 2001; Tang, Hettiarachchy, Ju, & Cnossen, 2002). Moreover, Chandi and Sogi (2007) have compared the functional properties of proteins from different rice cultivars.

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In addition to the role of whole-grain rice as a widespread food, the preparation of high-quality proteins as a by-product from brown or milled rice is still a challenging area of investigation. A high-protein variety of rice, Nutriar, with 30 g/100 g more protein than the usual cultivars, has been developed in the Julio Hirschhorn Experimental Station, (La Plata, Argentina) as a part of the Rice Program of the Facultad de Ciencias Agrarias y Forestales. The characteristics of this variety of protein have yet to be described.

The aim of this work was therefore to investigate the functional properties of the protein isolates from brown and milled Nutriar rice and compare these features with those of isolates from a standard rice cultivar, El Paso 144.

2. Materials and methods

2.1. Plant material

A high-protein–rice (*Oryza sativa L.*) cultivar, Nutriar FCAyF, and a standard rice cultivar, El Paso 144 ROU, were supplied by Programa Arroz de la Facultad de Ciencias Agrarias de la Universidad Nacional de La Plata. To obtain the milled rice, the husk and bran layers were removed by means of an experimental mill (universal type Guidetti and Artioli, Italy). Flour was obtained by grinding either brown or milled rice in an Udy mill (UDY Corporation & Alpha Plastic & Design, Fort Collins Co 80524) of 1-mm mesh, and sieving through a mesh of 10 mm.

2.2. Preparation of protein isolates

Flour of brown rice or of milled rice was suspended in water (1:10, w/v) and the pH adjusted to 12.0 with 2 mol equi/L NaOH. The suspension was stirred for 60 min at room temperature and then centrifuged for 30 min at 9000*g*. The supernatant was adjusted to pH 6 with 2 mol equi/L HCl and then centrifuged at 9000*g* for 20 min at 4 °C. The pellet was suspended in water, neutralized with 0.1 mol equi/L NaOH, and freeze-dried. The protein extracted was determined in the extracting solvent by the Lowry method.

2.3. Extraction of protein fractions

Protein fractions were extracted according to the Osborne method, with slight modification. The extraction procedure was conducted at room temperature with a meal/extraction solution ratio (w/v) of 1:10. Flour was treated with water to extract albumin and next with 32.5 mmol/L K_2HPO_4–2.6 mmol/L KH_2PO_4, 0.4 mol/L NaCl, pH 7.5 (buffer A), to extract globulin. Then, glutelin was extracted from the last residue with 0.1 mol equi/L NaOH. Prolamins were finally extracted with 70 mL/100 mL aqueous ethanol. After each treatment, the extracted residue was separated by centrifugation at 9000*g* for 20 min at room temperature.

2.4. Protein solubility

The solubility of the protein isolates was analyzed by preparing 1 g/100 mL suspensions either in water or in one of the following 0.2 mol/L Na salt buffers: 0.17 mol/L $C_6H_8O_7$/0.03 mol/L $C_6H_7O_7^-$ (pH 2.3); 0.08 mol/L $C_6H_8O_7$/0.12 mol/L $C_6H_7O_7^-$ (pH 3.1); 0.015 mol/L $C_6H_8O_7$/0.15 mol/L $C_6H_7O_7^-$/0.035 mol/L $C_6H_6O_72^-$ (pH 4.1); 0.11 mol/L $C_6H_7O_7^-$/0.09 mol/L $C_6H_6O_7^{2-}$ (pH 4.7); 0.06 mol/L $C_6H_7O_7^-$/0.14 M $C_6H_6O_7^{2-}$ (pH 5.1); 0.18 M $H_2PO_4^-$/0.02 M HPO_4^{2-} (pH 6.3); 0.12 M $H_2PO_4^-$/0.08 mol/L HPO_4^{2-} (pH 7.5); 0.132 mol/L H_3BO_3/0.068 mol/L $H_2BO_3^-$ (pH 8.8); 0.046 mol/L H_3BO_3/0.154 mol/L $H_2BO_3^-$ (pH 9.7); 0.128 mol/L HCO_3^-/ 0.072 mol/L CO_3^{2-} (pH 10.1); 0.03 mol/L HCO_3^-/0.17 mol/L CO_3^{2-} (pH 11.0); 0.163 mol/L $H_2BO_3^-$/0.037 mol/L HBO_3^{2-} (pH 12.2).

The samples were incubated for 1 h at room temperature with agitation by vortexing every 15 min followed by a centrifugation at 10,000*g* for 20 min at room temperature. Protein solubility was considered to be the protein content of the supernatants as a percent of the total protein content of the sample.

2.5. Determination of protein

The protein content of flour and isolates was determined by the micro-Kjeldhal method (AACC, 1983) through the use of the protein-nitrogen coefficient of 5.95 (Juliano, 1985).

The Lowry method was used in the following studies: in solubility and water-holding capacity analyses; to determine the protein extracted at pH 12.0 when preparing the protein isolates and to determine the yield of protein fractions.

2.6. Foaming properties

Assays were performed as described previously (Wagner, Sorgentini, & Añón, 1996). Nitrogen was bubbled at a flow rate of 1.70 mL/s through 6 mL of a 1.0 mg/mL sample of protein in borate buffer at pH 9 or citrate buffer at pH 3, both at 0.2 mol/L, as indicated below. The bubbling was continued for 1 min. The maximum volume of liquid incorporated in the foam (V_{max} mL) and the time for half-drainage of that incorporated liquid ($t_{1/2}$ min) were determined.

2.7. Emulsifying properties

The emulsions were prepared by homogenization of 14 mL of a given sample suspended in borate buffer, pH 9, 0.2 mol/L (at 1.5 mg/mL) with 10 mL of sunflower oil, by means of an Ultraturrax device (T-25, S25N10G, IKA Labortechnik, Karlsruhe, Germany) operating at 20,000 rpm for 90 s at 25 °C.

The emulsion stability was determined upon standing at 25 °C through the use of a Vertical Scan Analyzer (QuickScan, Beckman-Coulter, USA). The samples were loaded into a cylindrical glass measurement cell and the backscattering profiles (%BS) monitored every minute for 1 h as a function of the sample height (total height, 60 mm). Initial-backscattering ($\%BS_{in}$) values were determined from the starting profile of the emulsions ($t = 0$ min) as the mean value throughout the entire tube length. The creaming kinetic was followed by measuring $\%BS_{10-30mm}$, the mean values for %BS in the bottom zone of the measurement cell (between 10 and 30 mm) as a function of time. The stability parameters $t_{0.1}$, the time when $\%BS_{10-30mm}$ diminishes to 10% of its initial value, and the kinetic constant, $K_{0.1}$, where $K_{0.1} = (\%BS_{in10-30mm} \times t_{0.1})^{-1}$ h^{-1}, were then determined. The coalescence in the cream phase was analyzed by following the variation of the mean %BS in the upper zone of the tube ($\%BS_{50-60mm}$) as a function of stationary-storage time.

2.8. Water-imbibing capacity (WIC)

The WIC was assessed by means of a modification of the Baumann apparatus as described by Torgensen and Toledo (1977) and was carried out at 20 ± 2 °C. The spray-dried protein sample (30 mg) was spread on the wet filter paper and the volume of water absorbed against the gravity was determined at different times. Results were expressed as mL of water imbibed per g of sample (WIC) and time required to reach equilibrium (t_e).

Table 1
Flour-protein content and flour extracted-protein.

	El Paso 144 (E)	Nutriar (N)	Difference (N-E)
Protein in flour (g/100 g)[a]			
Milled flour	8.65 ± 0.03	10.36 ± 0.71	1.71 (19.8%)[b]
Brown flour	9.74 ± 0.05	12.42 ± 0.16	2.68 (27.5%)[b]
Extracted protein (g/100 g)[a]			
Milled flour	8.26 ± 0.58	10.72 ± 0.41	2.46 (29.8%)[b]
Brown flour	9.56 ± 0.51	12.67 ± 0.49	3.11 (32.5%)[b]

[a] g protein /100 g flour.
[b] protein difference as percentage of El Paso protein. Values are the average of duplicate measurements on the duplicate sample ± standard deviation.

2.9. Water-holding capacity (WHC)

Samples were first suspended in distilled water (at 1 g/100 mL]) by magnetic stirring with occasional vortex agitations for 1 h at room temperature (20 °C) then centrifuged at 10,000*g* for 30 min at 15 °C. The weight of the pellet (m_{hip}) and the supernatant-protein content (m_{sp}) were determined.

The WHC was calculated as:

$$WHC = (m_{hip} - m_{sp} + m_{tp}) \Big/ (m_{tp} \times \delta)$$

where m_{hip} is the mass (measured weight) of the hydrated insoluble protein obtained (*i. e.*, the weight of the pellet), m_{tp} the mass (anhydrous weight) of total protein in the sample (assuming the sample to be entirely protein), m_{sp} the mass (weight) of the soluble protein in the supernatant, and δ the density of water at room temperature. WHC is expressed as mL of water retained by the insoluble-protein fraction per gram of total protein (Petruccelli & Añón, 1994).

2.10. Statistical analyses

All determinations were performed in duplicate. Multifactor analysis of variance (ANOVA) of the variables was performed by means of Statgraphics Plus, a software package from Statgraphics Corp., Rockville, MD. Tukey's multirange test ($p < 0.05$) was used to compare the means of the different variables.

A correlation matrix was designed by means of the Statgraphics Plus software involving the different parameters of functional properties as measured under the same conditions of pH and ionic strength.

3. Results and discussion

The protein content of the new cultivar (Nutriar) was compared with the standard cultivar El Paso. As is shown in Table 1 the amount of protein of Nutriar milled flour is 19.8% greater than that of El Paso milled flour, whereas the Nutriar brown-flour protein content is 27.5% higher than the corresponding one from El Paso. These results indicate that the increase in protein content in the new cultivar is in greater proportion in the brown than in the milled flour.

Values in Table 1, also show that the difference in the extracted protein from the two cultivars is higher than the difference in the protein content of whole flours; this result suggests that Nutriar proteins are more easily extractable—e. g., more soluble in the extracting solvent—than the El Paso proteins. Moreover, the protein difference between the cultivars with respect to the extracted proteins, as opposed to the whole-flour protein contents, is less augmented when the brown flours are compared to the milled flours. This difference may be explained by a greater solubility of the endosperm proteins in the Nutriar cultivar than in the El Paso rice.

The weights of the protein fractions of the cultivars per 100 g of flour depicted in Table 2 show, as expected, a higher amount of albumins in the brown flours than in the milled flours, but there is no difference in the amount of this fraction between the corresponding Nutriar and El Paso flours. The amount of globulins and prolamins is similar among the four flours, whereas the glutelin content is higher in Nutriar flours than in El Paso ones. In both cultivars the glutelin content is higher in brown flour than in milled flour. This finding is rather unexpected since although endosperm protein might be present in milled rice, bran proteins (seed coat, pericarp, testa, and embryo) with very low content of glutelins are components of brown rice. This result therefore suggests that in the abrasive or friction milling some endosperm glutelins may have been lost. The combined data in Table 2 would indicate that the glutelin fraction is mainly responsible for the higher protein content of the Nutriar seeds and that Nutriar glutelin is more easily extractable than El Paso glutelin.

Table 2
Protein fractions in flours (mg/100 g flour).

	El Paso 144		Nutriar	
	Milled flour	Brown flour	Milled flour	Brown flour
Albumins	0.06 ± 0[b]	1.03 ± 0.04[a]	0.21 ± 0.01[b]	1.14 ± 0.05[a]
Globulins	0.62 ± 0.02[a]	0.89 ± 0.02[a]	0.80 ± 0.01[a]	0.65 ± 0[a]
Glutelins	6.90 ± 0.40[c]	7.59 ± 0.44[b]	7.98 ± 0.05[b]	10.18 ± 0.18[a]
Prolamins	0.57 ± 0.02[a]	0.63 ± 0.02[a]	0.29 ± 0[a]	0.39 ± 0.01[a]
Total	8.15 ± 0.44[c]	10.14 ± 0.51[b]	9.28 ± 0.05[bc]	12.36 ± 0.25[a]

Different letters within the same row mean significant differences ($P < 0.05$). Values are the average of triplicate measurements on the duplicate sample ± standard deviation.

Table 3
Abbreviation nomenclature and protein content of isolates.

Source	El Paso 144 Protein (g/100 g)[a]	Nutriar Protein (g/100 g)[a]
Milled-rice flour	Em (86.0 ± 0.4)	Nm (86.1 ± 0.9)
Brown-rice flour	Eb (77.4 ± 0.5)	Nb (83.3 ± 0.8)

[a] g/100 g isolate.

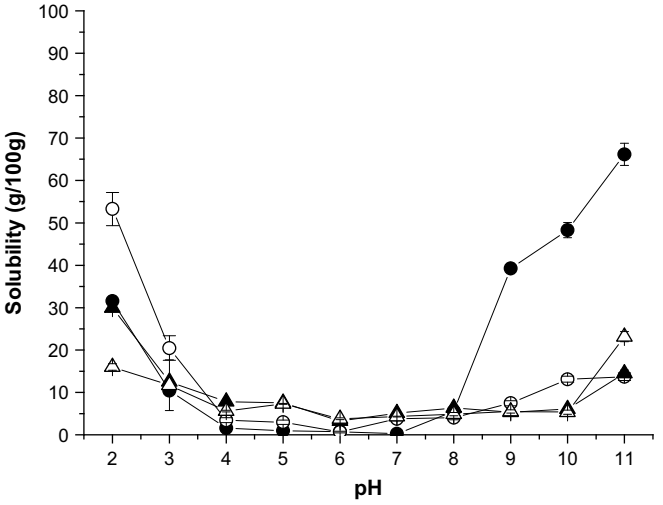

Fig. 1. Protein solubility at different pHs of rice-protein isolates from brown and milled Nutriar rice (Nb: ● and Nm ○ respectively) and from brown and milled El Paso 144 rice (Eb: ▲ and Em: △respectively).

Table 4
Foaming parameters of rice-protein isolates.

	pH	V_{max}[a](mL)	$t_{1/2}$[b](min)
Nb	3	1.83 ± 0.18c	0.51 ± 0.08c
Nm	3	4.66 ± 0.06b	0.96 ± 0.20b
Nb	9	5.11 ± 0.00a	1.52 ± 0.06a
Nm	9	1.39 ± 0.04d	0.41 ± 0.06c
Eb	9	0.54 ± 0.11e	0.56 ± 0.05c
Em	9	1.50 ± 0.11cd	0.64 ± 0.00bc

Different letters within the same column mean significant differences ($P < 0.05$).
[a] V_{max}: maximum volume of liquid incorporated to the foam.
[b] $t_{1/2}$ time for half-drainage of liquid incorporated to foam.

The abbreviation nomenclature and protein content of the isolates prepared from the four flours (according to 2.2) are summarized in Table 3. The functional properties of these different isolates were then studied.

3.1. Protein solubility

The protein solubility of the isolates at different pHs is shown in Fig. 1. The four isolates displayed a very low solubility within a wide moderate pH range but exhibited a significant higher solubility at extreme pHs (either high or low). This behavior is in accordance with the high glutelin content of rice proteins (AACC, 1983). Nevertheless, these isolates manifested some differences with respect to each other in their solubilities at extreme acid and alkaline pHs. Nb exhibited a significantly higher ($P < 0.05$) solubility than the other isolates at alkaline pHs, with the highest value (60 g/100 g) being at pH 11, similar to the solubility of a previously reported rice-bran–protein hydrolyzate (Tang et al., 2003). In contrast, Nm had a maximum solubility in acid media (at pHs 2 and 3). Considering the effect of the abrasive, frictional and milling processes on the physicochemical properties of rice kernel (Juliano, 1993), these differences might be ascribed to differing physicochemical characteristics of milled-flour proteins as the result of those processes. Protein isolates from the El Paso 144 cultivar (Eb and Em) were less soluble than those from the Nutriar. These results would suggest that the Nutriar-variety proteins exhibit certain structural properties that differ from those of the El Paso 144 cultivar. Considering the existence of two subfamilies of glutelin polypeptides that may exhibit differing degrees of polymerization (Katsube-Tanaka et al., 2004), it is possible that the Nutriar variety of rice is enriched in the subfamily showing lower degrees of polymerization.

3.2. Surface properties

Considering that at pH 9 and $\mu = 0.2$ mol/L isolates showed a higher solubility than at neutrality, the surface functional properties of the isolates were studied at that pH. The foaming properties of the Nutriar isolates (Nb and Nm) were studied at pH 9 and 3. Table 4 summarizes the values for the parameters obtained

Table 5
Emulsifying parameters of rice-protein isolates.

	$\%BS_{in}$[a]	$t_{0.1}$[b] (min)	$K_{0.1}$[c] (h^{-1})
Nb	26.47 ± 0.47a	6.02 ± 1.25a	0.38 ± 0.09c
Nm	17.71 ± 1.96b	2.10 ± 0.08b	1.62 ± 0.11a
Eb	19.11 ± 0.83b	3.33 ± 0.11b	0.94 ± 0.06b
Em	19.49 ± 1.84b	2.24 ± 0.04b	1.37 ± 0.05a

Different letters within the same column mean significant differences ($P < 0.05$).
[a] $\%BS_{in}$: initial-backscattering.
[b] $t_{0.1}$: time in which $\%BS_{10-30mm}$ decreases by 10%.
[c] $K_{0.1}$: kinetic constant.

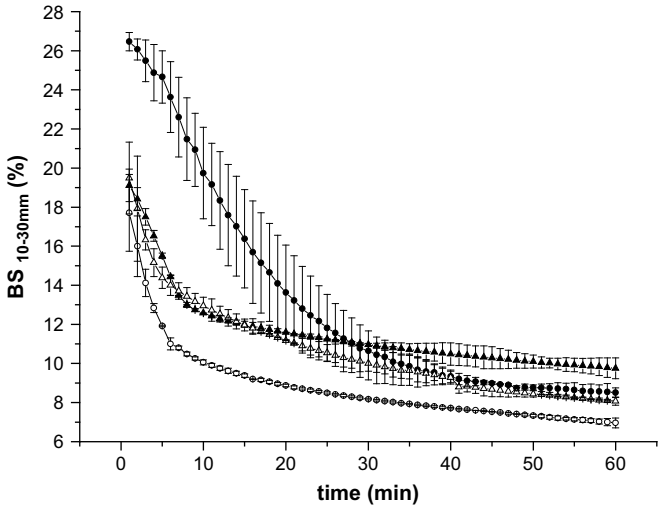

Fig. 2. Mean percent backscattering within the bottom zone of the tube ($\%BS_{10-30mm}$) at different times after stationary storage of emulsions prepared with the isolates Nb: ● Nm ○ Eb ▲ and Em: △ (*cf.* Table 3 for abbreviation nomenclature).

corresponding to the foaming properties of the isolates. At pH 9, the Nb isolate showed the highest foam-forming capacity, which is expressed as the maximum volume of liquid incorporated in the foam (V_{max}), as well as the highest foam stability, measured as the time for half-drainage of the liquid incorporated in the foam ($t_{1/2}$). This isolate displayed a better foaming property than a previously reported soybean isolate ($V_{max} = 2.96$, $t_{1/2} = 0.76$; Ventureira, personal communication); moreover, its foams were compact, consisting in small spherical bubbles. The other isolates (Nm, Eb, and Em) exhibited low foam-forming and -stabilizing capacities, and their foams were comprised of large polyhedral bubbles.

Table 4 also shows that the foaming properties of Nutriar isolates (Nb and Nm) at pH 3 were opposite to those obtained at pH 9. Whereas with Nb the values for V_{max} and $t_{1/2}$ were much higher at pH 9, with Nm the two parameters were greatly increased at pH 3. These results are in accordance with the solubility behavior of these isolates, with Nb and Nm exhibiting greatly enhanced solubilities at pHs 9 and 3, respectively (Fig. 1). This correlation would

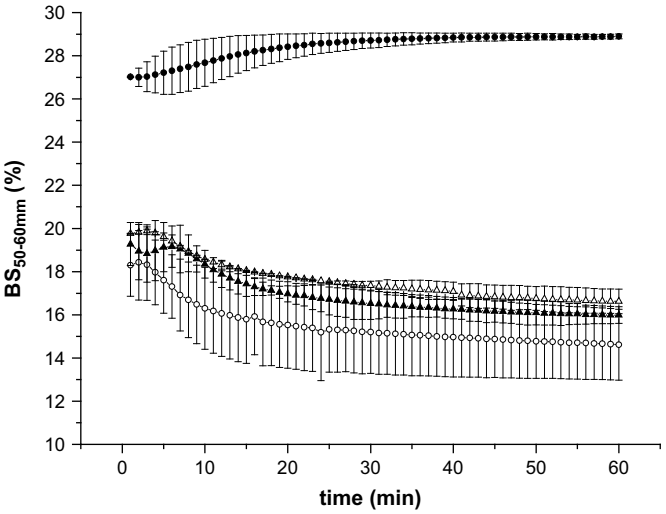

Fig. 3. Mean percent backscattering within the upper zone of the tube ($\%BS_{50-60mm}$) at different times after stationary storage of emulsions prepared with the isolates Nb: ●, Nm ○, Eb ▲ and Em: △ (*cf.* Table 3 for abbreviation nomenclature).

Table 6
Correlation matrix between functional-properties parameters (pH 9).

	Protein solubility	Foaming parameters		Emulsifying parameters	
	PS (g/100 g)	Vmax	$t_{1/2}$	$\%BS_{in}$	$t_{0.1}$
Vmax	0.9763[a]				
$t_{1/2}$	0.9710[a]	0.9520[a]			
$\%BS_{in}$	0.9515[a]	0.9252[a]	0.9624[a]		
$t_{0.1}$	0.9139[a]	0.8362[a]	0.9244[a]	0.9120[a]	
$K_{0.1}$	−0.8405[a]	−0.7311[b]	−0.8774[a]	−0.8985[a]	−0.9414[a]

[a] 1% significance.
[b] 5% significance. Emulsifying and foaming parameters as in Tables 2 and 3.

indicate that the presence of soluble protein is important in order to develop good foaming properties on the part of rice proteins.

The emulsifying properties were determined by analyzing backscattering (%BS) profiles. The initial-backscattering ($\%BS_{in}$), which parameter increases with the number of drops and with a decrease in droplet size (Palazolo, Sorgentini, & Wagner, 2004), is a measure of the capacity to generate emulsions. Of the four samples studied, the Nb isolate displayed the highest emulsifying capability (Table 5). The stability of emulsions was also determined by analyzing the kinetics of creaming at the bottom of the tube by means of the decrease in the creaming-kinetics parameter $\%BS_{10-30mm}$ as a function of time. Comparison among the parametric profiles of the four isolates (Fig. 2) reveals a slower decline in the Nb $\%BS_{10-30mm}$. The higher stability of Nb is indicated by the highest $t_{0.1}$ value and the lowest $K_{0.1}$ value (Table 5). Coalescence in the cream phase is illustrated in Fig. 3 showing the kinetics of the mean $\%BS_{50-60mm}$ values. The decrease in this parameter in the Nm, Eb, and Em emulsions indicates that coalescence is taking place and overcoming the increase in $\%BS_{50-60mm}$ from the creaming process. By contrast, the elevation in $\%BS_{50-60mm}$ in the Nb emulsion would suggest that coalescence is not a significant component in the destabilization process of that emulsion. All these results demonstrate that the Nb isolate is a considerably better emulsifying agent than the other three.

According to these results Nutriar-protein isolates showed a better surface functionality than the El Paso 144 preparations. We also observed different behaviors with Nutriar isolates obtained from milled (Nm) and brown (Nb) flours. The Nm isolates showed better functionality than the Nb in acid media, this isolate, which can be prepared from broken rice, would be a good ingredient to be included in acid-food formulations. On the other hand, Nb presented better properties than Nm at alkaline pH. The discrepant behavior of these isolates might be ascribed to the processing carried out to obtain the milled flour and to the presence of coat and embryonic proteins in Nb that may confer different physicochemical properties on the isolates. The structural characteristics of these isolates are being studied in our laboratory.

In accordance with the correlation between surface properties and solubility, the isolate that had the highest solubility at pH 9 (Nb) also exhibited the most advantageous surface properties. To assess this observation, linear-regression curves were plotted among the functional-properties parameters of the four isolates. Table 6 shows the resulting correlation coefficients. A highly significant ($p < 0.01$) correlation was observed between the foam and emulsifying parameters and the protein solubility. The negative correlation between $K_{0.1}$ and the other parameters is in accord with the inverse relationship between $K_{0.1}$ and emulsion stability. Regarding the relationship between the solubility and the emulsifying properties of proteins, opposite results have been reported. Whereas a positive correlation between the solubility of a protein and its ability to emulsify and stabilize an emulsion has been reported in a variety of studies (Voutsinas, Cheung, & Nakai, 1983), many authors, nevertheless, point to evidence that emulsifying properties and solubility are not always well correlated (Aoki, Taneyama, & Inami, 1980; Voutsinas et al., 1983). A positive correlation, however, between the solubility and foaming properties of rice concentrates (Bera & Mukherjee, 1989) and of rice glutelins (Agboola et al., 2005) at different pHs has been observed. Moreover, the results from our studies constitute further evidence for the principal involvement of rice soluble proteins in the development of the surface properties of rice-protein isolates.

3.3. Hydration properties

Since rice proteins generally exhibit a low solubility in neutral solvents and especially in water, and because insoluble proteins are mainly responsible for hydration properties (Sorgentini, Wagner, & Añón, 1995), we investigated the WIC and WHC of the isolates Nb, Nm, Eb, and Em. Table 7 shows those results along with the values for each of the isolates' solubility in water.

All of the isolates were nearly insoluble in water, though Nb did show a somewhat higher solubility than the others. The hydration properties WIC and WHC of the four isolates were similar, indicating good water-imbibition and -holding functionality, with values comparable to those in the literature for a soybean isolate (Gandhi, Khare, & Jha, 2000) and a rice-bran–protein concentrate (Chandi & Sogi 2007). The water uptake of the isolates Nm, Eb, and Em occurred rapidly (small t_e, Table 7), whereas Nb absorbed water significantly more slowly (high t_e, Table 5). Once again, the Nb isolate manifested here a distinctive behavior compared to the other three preparations, one likely attributable to differences in the Nb's composition, such as the presence of aggregates that do not allow a fast water-protein wetting interaction.

The values for hydration capacity of these isolates are similar to those considered critical for viscous foods such as soups and gravies (Aletor, Oshodi, & Ipinmoroti, 2002) therefore these isolates could be high-quality ingredients for any of those foods.

Table 7
Hydration properties of the rice-protein isolates.

	Solubility	WHC	Water-imbibition capacity	
	S (g/100 g)		WIC (mL)	t_e (min)
Nb	3.79 ± 0.28^{a}	7.17 ± 0.44^{a}	4.28 ± 0.30^{a}	15.0 ± 0.0^{a}
Nm	0.93 ± 0.42^{b}	4.46 ± 0.35^{ab}	4.07 ± 0.24^{a}	1.0 ± 0.0^{b}
Eb	1.81 ± 0.55^{b}	5.67 ± 1.29^{a}	3.19 ± 0.11^{ab}	1.5 ± 0.71^{b}
Em	0.35 ± 0.0^{b}	2.60 ± 0.27^{b}	2.85 ± 0.37^{b}	1.0 ± 0.0^{b}

t_e: time required to reach equilibrium. Values with the same letter are not statistically different (Tukey $P < 0.05$).

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